Software for Modelling and Analysis of Rover on Terrain

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ABSTRACT

Wheeled rovers traversing soft terrain are subjected to extensive testing to determine the slope climbing limits, obstacle limits, steering limits and drive torque/power requirements. To understand the wheel soil interaction and reduce the number of tests, simulation software enabling virtual runs of the rover on soft soil have been developed by Space agencies worldwide. In the present work, simulation software is developed to model the rover-soft terrain interaction. The tool is capable of generating uneven terrain, defining mechanical properties of soil, modelling obstacles and wheel interaction on soft terrain, providing skid steering for given turn radii, slip feedback to model rover motion and includes the effect of grousers on rover performance. The software coding is based on terramechanics theory, simplified to reduce computation and is implemented in FORTRAN using ADAMS/Solver. The modeling of rover is carried out with ADAMS/View which is used for preprocessing, extracting the wheel terrain contact forces and post processing. Matlab is used for generating the Triangular Irregular Network from the terrain coordinates which are used in the model to generate the terrain geometry. Using this simulation software performance of a low mass four wheeled lunar rover is estimated on flat/inclined terrain, straight/turning maneuvers, obstacle climbing and contingency situation involving motor failure. In this paper, the details of mathematical modelling and software development are presented along with the performance parameters obtained for aforementioned cases.

Keywords

Rover, simulation software, mathematical modelling, wheel soil interaction.

1. INTRODUCTION

Space exploration missions for interplanetary/lunar surface studies using rovers have gained momentum in the recent past. To evaluate the overall performance of rover mobility; design, development and testing of rovers is carried out by developing appropriate rover hardware platforms and single wheel test beds. The hardware platforms are quite expensive and it is very difficult to conduct all the tests under various situations in different terrains.

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In order to overcome this difficulty, GUI based simulation software are developed to support the mission by providing useful inputs to evaluate the performance of rover and prompt appropriate actions to achieve normal performance of the rover along intended path. Simulation software validated and updated by tests acts as a virtual platform for dry runs of the rover on simulated terrain before carrying out the real time maneuvers. This helps in exhaustive decision making on the rover mobility when it is climbing an obstacle, moving up a slope, steering, etc; during mission operations.

Dimitrios S. Apostolopoulos [1] formulated mathematical functions which capture quantitative relationships among configuration parameters (wheel diameter, wheel width), performance parameters (drawbar pull, maximum gradable slope) and environmental/task parameters (soil geophysical properties, density, friction and size of obstacles). The locomotion synthesis (LocSyn) thus developed has been implemented on planetary rover, NOMAD. In Spacecraft Mechanisms Group, ISAC [2], a four wheeled rover was tested on flat, inclined terrain and on step. The modeling was carried out in ADAMS/View and the current characteristics of the motor were used to correlate generated torques.

European Space Agency (ESA) has developed Rover Chassis Evaluation Tool (RCET) [3] which estimates wheel soil interaction parameters using a Traction Prediction Module assuming 2D rover on 2D terrain. Nildeep et. al. [4], Surrey Space Centre, have developed Rover Performance Evaluation Tool (RPET) which consists of Rover Mobility Performance Evaluation Tool (RMPET) and Mobility Synthesis (MobSyn). RMPET provides selection of mobility system viz. wheeled, tracked and legged, stored terrain simulants viz. Mars Soil Simulant (MSS-B), Lunar terrain, Terrestrial soil (Earth) and user defined soil (customized soil with desired soil properties).

Aesco Soft Soil Tire Model (AS^2TM) [5] developed by AESCo GbR, Automotive Engineering Software & Consulting , Hamburg, offers wheel soil interaction model as a Simulink S-Function. Robert Bauer et. al. [6] have developed a Rover Chassis, Analysis and Simulation Tool (RCAST) to study mobility and support rover chassis design and optimization. Recent development in the Rover Analysis, Modeling and Simulation (ROAMS) [7] focus on the wheel-terrain contact model used in the ROAMS simulator. The ROAMS simulator can be used in stand-alone mode, for closed-loop simulation with on-board software, or for operator-in-the-loop simulations.

At Spacecraft Mechanisms Group (SMG) of ISRO Satellite Centre (ISAC), Software for Modeling and Analysis of Rover on Terrain (SMART) has been developed to simulate rover mobility on virtual terrain which will be useful for future interplanetary missions.

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The software is generic in nature and can be used for rover with any number of wheels, variable soil properties and different terrain geometries. It is a complete in-house development utilizing features of available commercial software like ADAMS and Matlab supplemented with terramechanics theory based mathematical formulations. Main features of SMART are terrain generation, simplified wheel soft soil interaction model, obstacle resistance model, skid steer resistance model, grouser model, slip feedback model and contingency model for motor failure.

The paper is organized as follows. In Section-2, the mathematical modelling of terrain, rover and wheel soil interaction is presented. Section-3 describes the code development and the features of SMART. In Section-4, the performance estimate of a four wheeled low mass lunar rover is presented.

2. MATHEMATICAL MODELLING AND FORMULATION

In this Section, mathematical modeling of rover, terrain, wheel soil contact, slope, obstacle, steering, contingency situation and grousers is presented. The rover considered for analysis is four wheeled, with a total mass of 20 kg, wheel radius of 90 mm, wheel width of 50 mm, wheel base of 600 mm and wheel stance of 500 mm, moving under lunar gravity.

2.1 Rover Mathematical Modelling

Unigraphics/NX (UG-NX 7.5) generated CAD models of the rover parts are imported in parasolid format into ADAMS (ADAMS/View 2012) and the dynamic model consisting of necessary joints and contact definitions is generated. Figure 1 shows the dynamic model of the four wheeled rover considered for simulation.

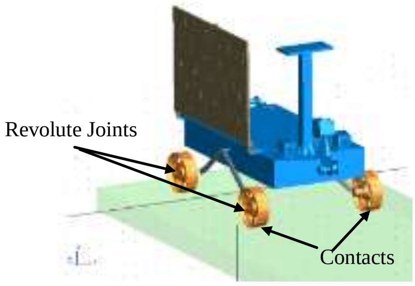

Figure 1. Dynamic model of four wheeled rover

2.2 Terrain Modelling

ADAMS Road Definition File (RDF) is used to generate the terrain. RDF uses Triangular Irregular Network to form any standard (flat, inclined) or uneven terrain, for which nodal connectivity and nodal coordinates are required. The nodal coordinates and connectivity matrix are generated using Matlab -7.12.0 (R2011a), as shown in Figure 2.

A combined terrain consisting of slope, uneven surface, dunes etc., can be generated using number of such RDF files. Contact between the wheel and terrain is defined using ADAMS contact algorithm using a static friction coefficient of 0.8. Other parameters used in contact force definition and solver settings are shown in Table 1.

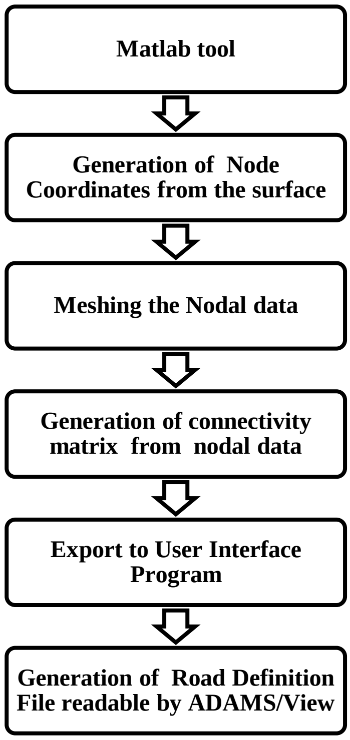

Figure 2. Generation of RDF using Matlab

ADAMS contact algorithm is used to obtain the normal contact forces between wheel and soil. These forces are required in wheel soil interaction algorithm to obtain the wheel sinkage, slip, traction and other performance parameters. ADAMS contact algorithm is also used for wheel-obstacle contact modeling.

Table 1. Wheel terrain contact definition (ADAMS)

Parameter	Value
Stiffness (N/m)	1e8
Damping (Ns/m)	1e6
Exponent	2.2
Maximum penetration depth (m)	0.001
Static friction coefficient	0.8
Dynamic friction coefficient	0.79
Velocity at which static friction attains maximum value (m/s)	0.10
Velocity at which dynamic friction attains maximum value (m/s)	0.11
Solver	GSTIFF
Formulation	I3
Minimum no. of steps for 1 sec	1000

2.3 Soil Contact Modelling

Performance assessment on soft soil as carried out by engineers from different fields like Aerospace and Agriculture, have used Terramechanics theory as proposed by Dr. M.G. Bekker and later modified by Wong & Reece [8-10]. The same theory has been used previously in SMG, ISAC [11] to evaluate the performance of four wheeled rover on different soils. The calculations in this study used numerical integration to evaluate the entry angle of wheel and then the resistance, traction, drawbar pull and drive torque as a function of wheel slip. To make the computation less expensive H. Shibley et. al. [12] have developed an

approximate model based on two assumptions; first, the normal stress profile is assumed to be linear and second, the peak normal stress is assumed to occur at mid angle of the wheel entry angle. As a result, iterative calculation is required only once to evaluate the entry angle and subsequent calculations are carried out using closed form equations.

In the present study, a full rover simulation incorporating wheel soil interaction models for each wheel terrain contact have been implemented based on extended simplified terramechanics equations. The basic model that evaluates the sinkage and soil resistance initially is based on H. Shibley et. al. [12] and the equations for steering resistance [13-14], grouser interaction [8], boulder resistance, sliding resistance under contingency situation are formulated incorporating assumptions wherever necessary and added to the basic model.

Assumptions made for the mathematical modelling of wheel soil contact are as follows:-

1. Wheel is circular, rigid and smooth: Implies that there is no grouser action on account of wheel roughness.
2. Wheel slip occurs due to soil friction only: Implies that due to adhesion, soil is always stuck on to the wheel surface and relative slip does not happen between wheel and soil.
3. Bulldozing resistance is zero: Implies that soil resistance is due to compaction only. This is valid for rear wheel because it rolls on beaten track. For front wheel bulldozing resistance is ignored as its magnitude is less compared to the compaction resistance for low normal loads. However, for skid steering, it is calculated and implemented.
4. Soil is inelastic: Implies that there is no soil recovery on the rear side of wheel.
5. Normal stress distribution is linear: This simplifies the formulation and will be explained further in this Section.
6. The peak normal stress occurs midway of the wheel entry angle: With this assumption, the peak stress location becomes independent of the wheel slip and simplifies the formulation. Under the same assumption, shear stress peak occurs at the same location as the normal stress.

Formulations for rover moving on a slope, climbing an obstacle and skid steering are discussed in greater detail in the subsequent sections. The different operating conditions and assumptions for each of these case studies have been discussed under appropriate sections. In the present study, mathematical modeling has been carried out for a four wheeled rover.

A driven rolling wheel is shown under static equilibrium in Figure 3.

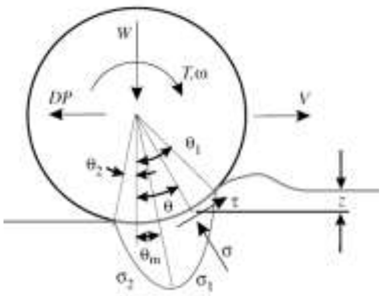

Figure 3. Free body diagram of a driven rigid wheel on deformable soil [9]

W = wheel load, T = wheel torque, ω = angular wheel velocity, σ = normal stress, τ = shear stress, z = wheel sinkage, θ_1, θ_2, θ_m = soil entry/exit/ peak normal stress angle

Under assumption 4 and 5, exit angle θ_2 is assumed to be zero and the normal stress variation is assumed to be linear over the angular contact respectively. Also, $\theta_m = \theta_1 / 2$ is assumed to be location of peak normal (σ_m) and shear stress (τ_m). Mathematically, the equations for normal and shear stress are written as follows:-

$$\sigma_1(\theta) = \frac{\theta_1 - \theta}{\theta_1 - \theta_m}\sigma_m \tag{1}$$

$$\sigma_2(\theta) = \frac{\theta}{\theta_m}\sigma_m \tag{2}$$

$$\tau_1(\theta) = \frac{\theta_1 - \theta}{\theta_1 - \theta_m}\tau_m \tag{3}$$

$$\tau_2(\theta) = \frac{\theta}{\theta_m}\tau_m \tag{4}$$

Under the assumption that peak normal and shear stress occur at the same point, following relationship can be written for the peak shear stress τ_m.

$$\tau_m = (C + \sigma_m \tan\varphi)(1 - e^{-\frac{r}{2k}[(\theta_1 - \theta_m)((1-s)-(1-s)\cos\theta_1)]}) \tag{5}$$

where, C = soil cohesion, φ = soil internal friction angle, k = shear deformation modulus, s = wheel slip, r = wheel radius. Using Equations (1) to (5), equations for normal load, drawbar pull, soil resistance and drive torque are derived. These equations have been implemented using FORTRAN subroutines. With the simplified normal load equation, entry angle θ_1 is obtained iteratively assuming slip to vary from 0 to 100%. Drawbar pull is worked out for each entry angle corresponding to each slip value and the slip at which drawbar pull is zero is evaluated.

For rover motion on slope, obstacle and during skid steering, the resistances are evaluated and considered in drawbar pull calculation to evaluate wheel slip. Drawbar pull, soil resistance and drive torque equations are closed form solutions that reduce computation avoiding numerical integrations. Each of the rover wheels is given an initial constant velocity for a small duration, after which the evaluated slip is feedback to the motion input so that the rover motion is simulated accurately. To check the efficacy of the simplified equations, a comparison is made with the terramechanics solution. It is found that the simplified equations give conservative estimate of the performance parameters. Johnson Space Centre (JSC) -1A soil properties have been considered for analysis, as shown in Table 2. K_c , K_φ , n and k are taken from Lunar Sourcebook [15] whereas C and φ have been measured by Engineering Consultancy Centre, NIT-Trichy.

Table 2. JSC-1A simulant properties

Property	Value
Cohesive module of deformation , K_c (N/m^n)	1400
Frictional module of deformation , K_φ (N/m^{n+1})	820000
Sinkage exponent , n	1.0
Cohesion, C (Pa)	1373.0
Angle of internal friction, φ (deg)	41.0
Shear deformation modulus, k (cm)	1.78

2.4 Slope resistance model

As the rover climbs up a front slope (refer Figure 4), the normal loading in front and rear wheels gets modified. The rover tilt angle is measured using markers placed on stationary part of front and rear wheels. The rover weight component acts in addition to the soil resistance and is assumed to be shared equally by all the wheels. From the simulation, wheel slip values over a slope varying from 0^0 to 20^0 are obtained.

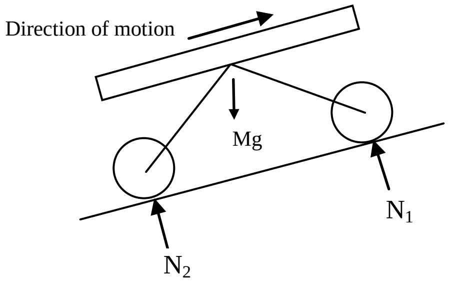

Figure 4. Rover climbing up a slope

When the rover moves down, weight acts in the direction of motion. In this case, the negative angle measured by markers is rounded to zero and gravity resistance is not considered. When the rover stands on a side slope (refer Figure 5), normal contact forces get redistributed among the left and right wheels of the rover. The contact between the side face of the wheel and soil has been ignored for ease of computation.

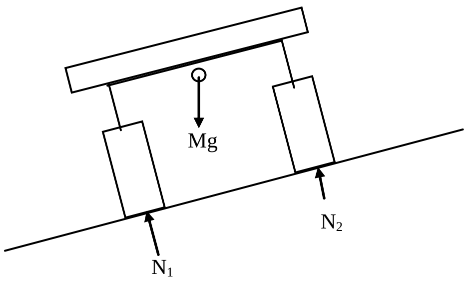

Figure 5. Rover moving on a side slope

2.5 Obstacle resistance model

The horizontal component of contact force 'N_o' at the wheel obstacle contact point resists the rover motion (refer Figure-6). This force is obtained from ADAMS and shared to all the wheels equally, that acts as resistance over and above the soil resistance. For the wheel in contact with obstacle, friction contact model of ADAMS is used whereas for the wheel in contact with soil, slip is obtained from the wheel soil interaction subroutine.

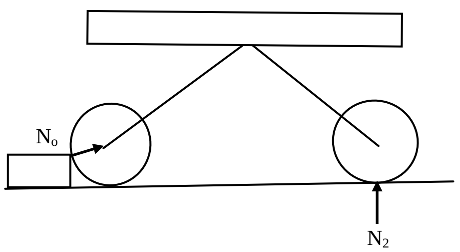

Figure 6. Rover climbing up a step

2.6 Skid steering model

By providing different velocities to the inner and outer wheels, the rover skid steers and traces a curve. During this maneuver, the wheel shears the soil at its contact surface and also pushes (bulldozes) soil at its side. Figure 7 shows the two components of steering resistance force. The shear force is obtained in the same way as traction force for longitudinal motion.

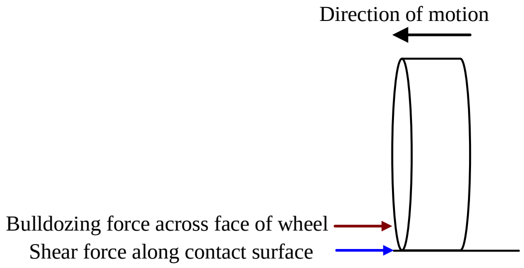

Figure 7. Shear & bulldozing resistance for steering wheel

The wheel slip angle (β) i.e. the angle between the wheel heading and rover velocity vector is required as an additional input for the calculations. Shear resistance in skid steer depends on the slip angle; hence the shear stress equation (5) gets modified as follows: -

$$\tau_m = (C + \sigma_m \tan\varphi)(1 - e^{-\frac{r}{k}[(1-s)(\theta_1 - \theta)\tan\beta)]}) \qquad (6)$$

The shear stress is integrated over the contact area to obtain the shear resistance R_s. The bulldozing resistance per unit width (R_b) is given by:-

$$R_b = D_1\{h(\theta)C + \frac{1}{2}\rho z^2(\theta)D_2\} \qquad (7)$$

where,

$$D_1 = \cot(X_c) + \tan(X_c + \varphi)$$
$$D_2 = \cot(X_c) + \frac{\cot^2(X_c + \varphi)}{\cot(\varphi)} \qquad (8)$$
$$X_c = 45^0 - \frac{\varphi}{2} \qquad (9)$$

ρ = weight density of soil

Wheel sinkage 'z' is a function of soil angle 'θ', but for ease of computation, a nominal value of 'z' corresponding to 'θ_m' has been used in the above equation. Total bulldozing resistance is obtained by multiplying 'R_b' with the contact projected length i.e. r $\sin\theta_m$. Both these resistances are assumed to act along the wheel axis direction at contact point below the wheel centre, as shown in Figure 8. The inner wheel is assumed to overcome the soil resistance in forward motion only whereas the outer wheels provide the additional traction to overcome the resistance moment.

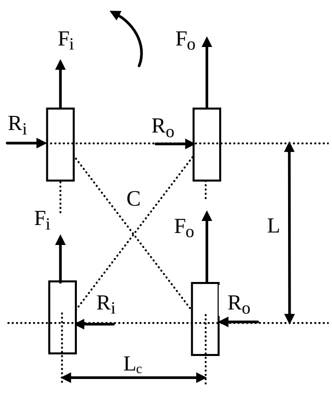

Figure 8. Free body diagram of rover during skid steering

The moment equation about the rover centre 'C' is written as:-

$$(R_i + R_o)\, L/2 = (F_o - F_i)\, L_c /2 \qquad (10)$$

where , R_i and R_o are the steering resistance of inner and outer wheels and F_i and F_o are the wheel traction in inner and outer wheels respectively.

With this equation $F_o - F_i$ is obtained as the additional traction required by the outer wheel to overcome the resisting moment. This value is added to the wheel resistance of outer wheel over and above the soil resistance already calculated. The following equation is used to obtain the velocity ratio ($K_s = V_o / V_i$) for a given turn radius 'R' assuming zero slip :-

$$K_S = \frac{2R + L_C}{2R - L_C} \qquad (11)$$

2.7 Resistance on account of motor failure

If one of the wheel motors fail to operate, the wheel skids in soil. The soil resistance due to sliding shear is given by:-

$$R_s = (C + \sigma \tan \varphi)\, r\, b\, (1 - \sin \theta_1) \qquad (12)$$

where σ is assumed as $\sigma_m /2$ .The bulldozing resistance is calculated using Equation (7) by multiplying it with wheel width 'b'. The total resistance so obtained is assumed to be shared equally by the remaining three wheels.

2.8 Grouser model

Grouser provides additional traction over and above the shearing action of soil by the circular portion of the wheel. Figure 9 shows the direction of grouser traction F_g. The grouser traction is given by following equation [8]:-

$$F_g = b\{\frac{1}{2}\gamma h_b^{\,2} N_\varphi + \sigma h_b N_\varphi + 2C h_b \sqrt{N_\varphi}\} \qquad (13)$$

where, $N_\varphi = \tan^2 (45^0 + \varphi/2)$ known as flow value
h_b = grouser height

As the normal stress varies from entry to exit angle, the grouser traction also varies during rotation of wheel. To make computation easy, a mean value of normal stress at mid angle θ_m is used for σ.

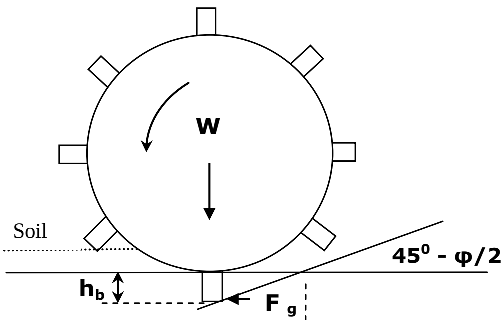

Figure 9. Grouser developing traction F_g for rolling wheel

F_g so obtained is added to the traction calculated earlier from the shearing action of circular rim portion of the wheel over soil. The bulldozing action of the grouser against the soil is only considered and the shear of soil along the grouser height is ignored.

3. SOFTWARE IMPLEMENTATION

This section provides the details of the different macro constituents and the software implementation of the hardware under study. After the generation of dynamic model of the rover from the geometric model, it is necessary to create data variables to hold the output values from all the wheels and to perform post processing to evaluate the performance of the rover during simulation. Manually creating variables for all the parameters to be monitored and for all the wheels is time consuming. Hence a macro is developed and executed in order to create the variables and are linked with the user written subroutines during run-time.

3.1 Macro

A macro is a user defined command file containing a series of executable ADAMS/View commands that helps in automating the repetitive procedures. Figure 10 shows a dialogue box for reading an existing command file containing the series of commands to be executed as a macro.

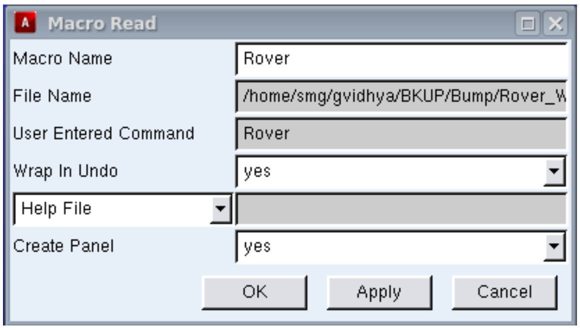

Figure 10. Dialogue box for Macro Read

The variables such as wheel contact force, wheel sinkage, nominal slip, resistance torque due to soil, drawbar pull, soil resistance, obstacle resistance, bulldozing and shear resistance are created at the end of execution of macro. Necessary arguments are defined in the macro in order to invoke the user written subroutines during run-time. The argument list contains the wheel id, contact id, contact element torque magnitude from ADAMS, angle marker ids for calculating front slope and any other necessary parameters that needs to be passed as inputs to user subroutine. Similarly all the required output variables can be created using the macro.

3.2 User Interface

A GUI has been created to display a dialogue box for entry of input data such as rover physical parameters and soil properties. A dialogue box for the inputs is shown in Figure 11.

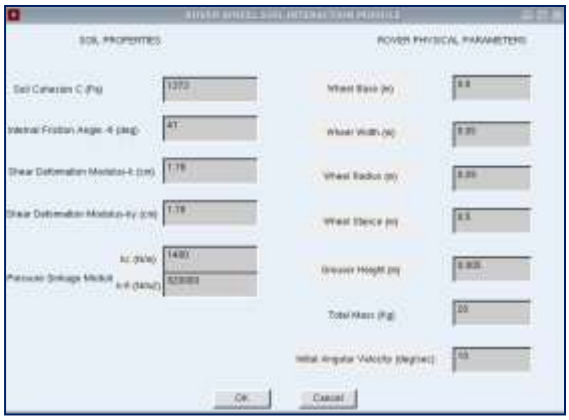

Figure 11. Input GUI of the wheel soil interaction module

3.3 Invoking Subroutines

User written subroutines can be invoked from statements or commands. After writing the custom subroutine, it is compiled with FORTRAN compiler and an ADAMS/Solver user library file is generated for linking with ADAMS/View during run-time. Flowchart shown in the Figure 12 describes the process of implementation of closed form terramechanics equations and computation of net traction and total resistance.

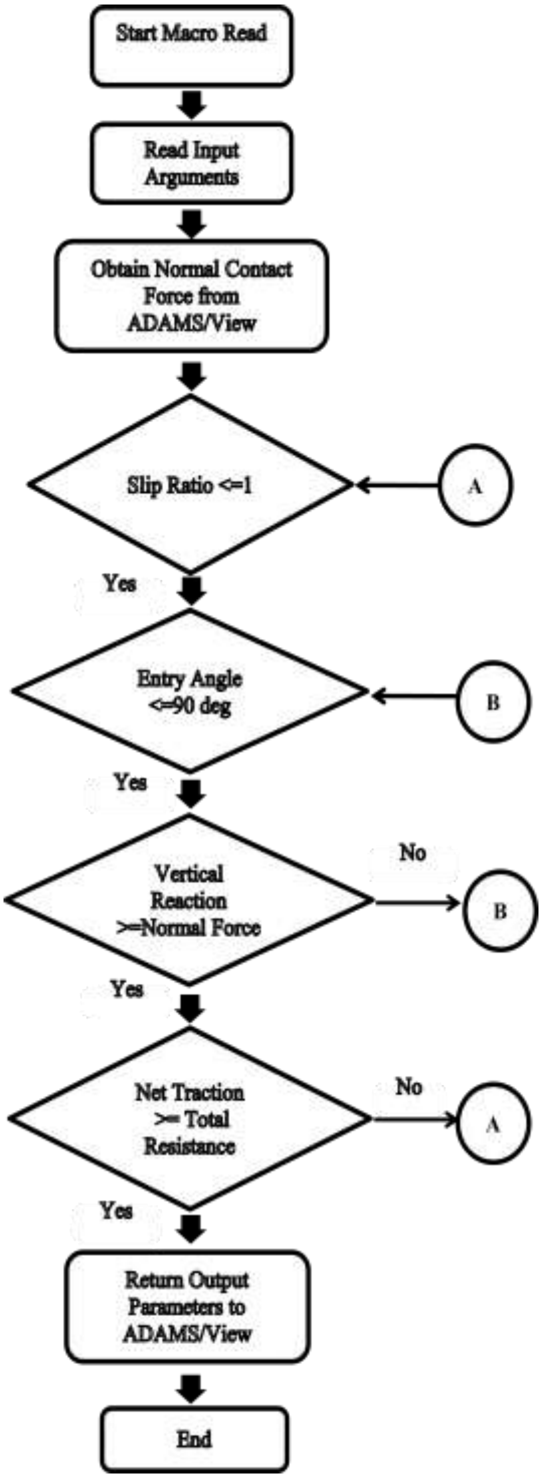

Figure 12. Mathematical formulation flowchart

4. ROVER PERFORMANCE ON BENCHMARK TESTS

A four wheeled rover moving under lunar gravity, as presented in Section 2.0, is considered for analysis. The rover is moved on different terrains like flat, uneven and sloped. Obstacle climbing capability is also analysed. Skid steering is carried out on an uneven terrain. Contingency situation involving motor failure is analysed. Effect of grouser on performance is evaluated over a slope.

4.1 Rover moving on a flat uneven terrain

Figure 13 shows the basic terrain over which the code implementation is validated with terramechanics solution.

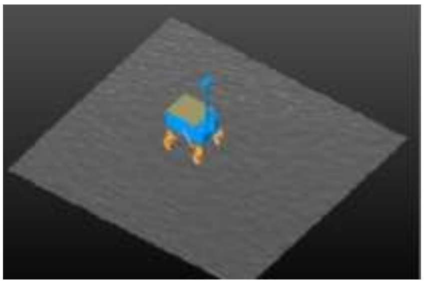

Figure 13. Rover moving on a flat uneven terrain

Owing to rover weight of 20 kg mass, moving under lunar gravity, a load of 8 N is observed on each wheel of four wheels. The peak normal stress σ_m obtained is 7.7 KPa. This makes the rover sink in soil by 11.28 mm for an entry angle of 0.53 rad. Wheel slips by 13% so that the drive torque is 0.2 N-m. Normal force curves are shown in Figure 14.

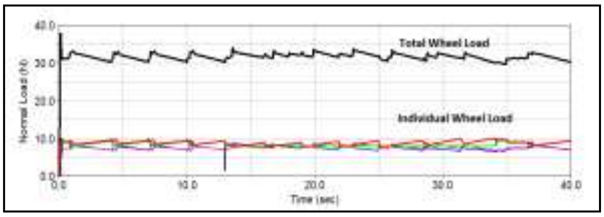

Figure 14. Normal Wheel Load Vs Time

The normal force variation is periodic in nature due to presence of grousers; the summation of the forces is nearly constant throughout the motion and equals rover weight. The simplified solution is compared with terramechanics solution as shown in Table 3.

Table 3. Comparison of performance parameters

Parameter	Simplified solution	Terramechanics solution
Sinkage (mm)	11.28	8.6
Slip (%)	13.0	10.0
Drive torque (Nm)	0.2	0.15

As observed, the results of simplified solution are comparable with the terramechanics solution, conservative in nature, and hence can be used to predict the rover behaviour on soft soil.

4.2 Rover climbing up a slope

A parabolic terrain with slope increasing up to 20^0 is modelled as shown in Figure.15. It is observed that the slip in the wheels increases with increasing slope and the front wheels slip more than the rear wheel.

As shown in Figure 16, for a slope of 20^0, the slip in front wheel is 65% and in the rear wheel is 45%. The resisting torque for the front wheel is found to be 0.75 N-m and for the rear wheel it is 0.9 N-m.

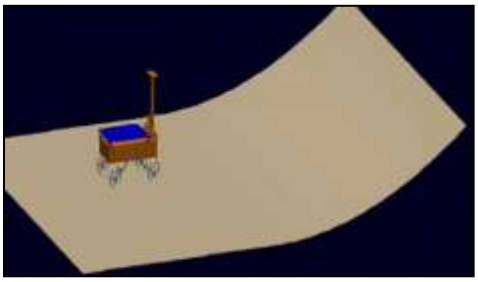

Figure 15. Rover moving on a parabolic terrain

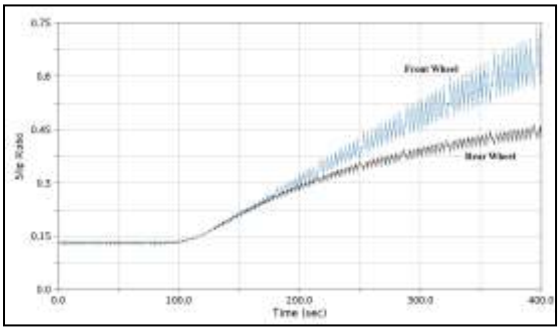

Figure 16. Slip Ratio Vs Time for upward slope

4.3 Effect of grousers

A rigid wheel with 15 numbers of grousers of 5 mm height is considered for study. It is observed that on a flat surface, wheel with grousers does not slip and on a slope of 20^o the slip in front wheel reduces from 65% to 26% and that in rear wheel reduces from 45% to 6%, as shown in Table 4.

Table 4. Wheel slip variation with grousers

Slope (deg)	Front Wheel Slip (%)	Rear Wheel Slip (%)
5	1	0
10	7	1
15	15	2
20	26	6

4.4 Rover negotiating a boulder on uneven terrain

A boulder in the shape of an ellipsoid of height 50 mm is placed in front of the rover. The movement of rover with grousers climbing an obstacle without differential/with differential are shown in Figure 17(left) and 17(right) respectively.

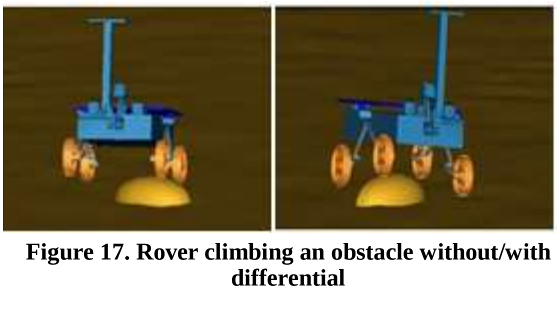

Figure 17. Rover climbing an obstacle without/with differential

As observed in Figure 17(left), wheels tend to lose contact with ground if differential mechanism is not incorporated. Figure 17(right) indicates the relative position of wheels when the differential mechanism is active. The obstacle resistance in front and rear wheels are shown in Figure 18.

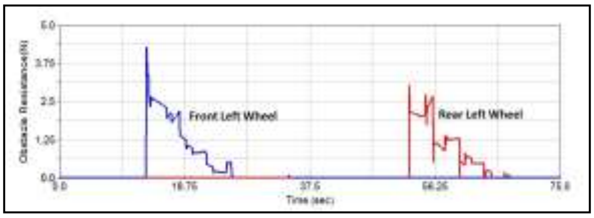

Figure 18. Obstacle resistance variation

As observed, the value of obstacle resistance is maximum when the wheel just lifts over the obstacle and reduces to zero when it reaches the maximum height of the obstacle

4.5 Rover steering on flat uneven terrain

By providing differential velocities to outer and inner wheels with grousers, different turning radii are achieved. A typical turn radius of 1.0 m is shown in Figure 19.

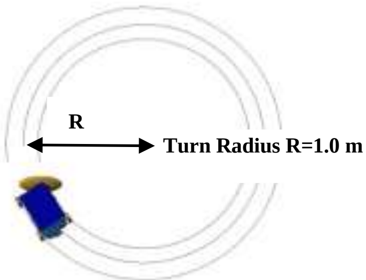

Figure 19. Rover steering on a flat uneven terrain

For a given velocity ratio, theoretical turn radius is calculated. The slip value of the wheel as calculated by wheel soil interaction subroutine is fed back to individual wheels. This results in increased turn radius. Table 5 shows the variation in wheel slip for the outer/inner wheels for different turning radii. As estimated, the actual turn radius obtained is more than the required turn radius due to wheel slip. For smaller turn radii, the wheels tend to slip more. For point turn, the outer wheels slip by 90% which may make the rover immobile. It is observed that the outer wheels slip much more than the inner wheels.

Table 5. Turn radius variation with velocity ratio

Velocity Ratio (K_s)	Theoretical Turn Radius (m)	Estimated Slip (%)		Estimated Turn Radius (m)
		Outer	Inner	
1.66	1.0	28	0	2.81
2	0.75	38	0	2.33
3	0.50	48	0	1.14
-1	0	90	0	0

4.6 Contingency situations

If driving motor fails to operate, the wheel would drag and the sliding resistance would be shared by other wheels. Considering one rear motor not working, the rover motion is simulated on an uneven terrain. The rover has a tendency to take a turn on account of imbalanced moment as shown in Figure 20. For the present configuration, the soil resistance

due to wheel sliding is 12.0 N which implies that the driving wheels should develop additional traction of 4.0 N each.

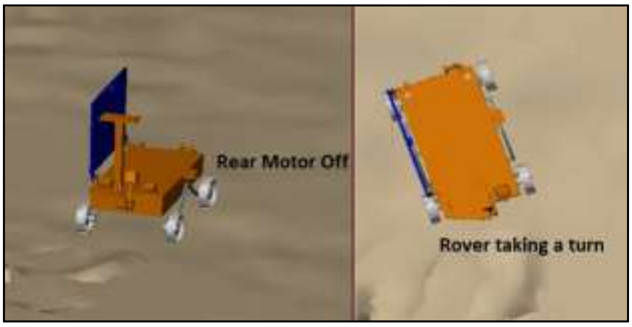

Figure 20. Rover motion under contingency situation

A four wheeled rover configuration has been realized and the performance was qualitatively observed on a sandy slope and a rigid step. It was found that the rover could climb 50 mm step. It could also traverse a 20^0 sandy slope with permissible wheel slip.

5. CONCLUSIONS

A wheel soil interaction module based on simplified terramechanics theory, ADAMS contact force algorithm and ADAMS Pre/Post Processing features, has been developed. The tool provides means to generate uneven terrain, define soil properties and construct virtual run as per user requirement.

Using this tool, case studies have been carried out for a four wheeled rover to simulate its motion on flat/inclined terrain, skid steering, obstacle climbing and contingency situation. Performance parameters like sinkage, slip, drive torque, resistance, and drawbar pull have been obtained as output.

In future, it is planned to validate and update the mathematical models by comparing the performance with actual rover on terrain test bed.

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